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Abstract

Due to tight public budget constraints, the efficiency of publicly financed universities in Germany is receiving increasing attention in the academic as well as in the public discourse. Against this back ground we analyze the efficiency of 72 public Ger-man universities for the y ears 1998–2003, applying data envelopment and stochastic frontier analysis. Contrary to earlier studies we account for the faculty composition of universities, which proves to be an essential element in the efficiency of higher education. Our main finding is that East German universities have performed better in total factor productivity change compared to those in West Germany. However, when looking at mean efficiency scores over the sample period, West German universities still appear at the top end of relative efficiency outcomes.

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Keywords: Universities, efficiency, data envelopment analysis, stochastic frontier analysis.

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1 Introduction

Human capital is an important factor for economic growth and consequently the efficiency of the educational system plays a major role in the political and scientific discussion. The number of students as well as their educational achievements are crucial in the formation of human capital and thus for the future competitiveness of the German economy.

The vast majority of German universities are publicly financed. Due to tight public budgets, university finance has come under severe pressure in recent years.[1] The share of university spending to total government spending has decreased from about 6.6% in 1975 to about 5% in 2003 while the number of students has more than doubled. In the 1975-1990 period aggregate university spending has increased by about 2.2% on average in real terms. Spending growth from 1998 to 2004 has decreased to a yearly average of about 1.3% while student numbers have increased by 2% in the same period.[2] Moreover, international comparisons show that in Germany public spending on tertiary education as a share of GDP is below the OECD mean. Consequently, there is a public and academic discussion about more private funding in the German university landscape. In this context, many federal states are currently introducing tuition fees in public universities.

While additional fund raising represents an option to improve the financial situation of the universities, we focus on the efficiency of public universities in Germany. Regardless of privatization or tuition fees, information about university efficiency performances is essential in times of scarce public resources. For instance, knowledge about university efficiency enables university management to recognize shortcomings and improve their performance. In addition, state governments, which are responsible for financing universities in Germany, can use efficiency indicators as a guideline for the distribution of funds among the universities and thus create an atmosphere of competition within the public university system.

[1] University finance is a major responsibility of the German states, which account for about 90% of spending on higher education. The federal level contributes about 10% to university finance while the local governments are not involved at all.

[2] German reunification complicates pre-1990 and post-1990 comparisons. In addition, in 1997 a major change in the university statistics was introduced that makes it virtually impossible to compare data from the period before 1997 to data after 1997.

Special attention will be paid to the performance of East German universities, since these institutions have undergone major changes since German reunification. Moreover, the East German states will be confronted with a dramatic decline in local high school graduates beginning in 2008 and resulting in a 40 percent drop in 2020 compared to the current level as the latest projections of the Kultusministerkonferenz (2005) show. Hence, the associated decrease in student numbers implies that demographic change will also exert significant pressure on efficiency in East German universities .

Given the importance of efficiency analysis in the education sector, it comes as a surprise that the efficiency of higher education in Germany has not been subject to intensive investigation. The studies by Warning (2004, 2005) are notable exceptions. So far mainly surveys among students and professors have been conducted resulting in university rankings. However, the aim of these rankings has not been the investigation of university efficiency but rather the quality of education in specific fields of study.

Against this background, we study the efficiency as well as total factor productivity change of publicly financed universities in Germany. Applying data envelopment analysis (DEA) and stochastic frontier analysis (SFA) for 72 German universities for the years 1998-2003, we find that total factor productivity has been increasing more rapidly in East German universities. However, when looking at mean efficiency scores over the sample period, West German universities still appear at the top end of relative efficiency outcomes.

The remainder of this paper is organized as follows. In Section 2 the relevant literature on measuring (in-)efficiency of institutions in higher education is reviewed. Section 3 provides information on the data set and specifies the input and output variables. In Section 4 and 5 we develop our DEA and SFA models and present the empirical findings. Section 6 compares and contrasts the results from DEA and SFA while Section 7 summarizes our findings.

2 Related Literature

The vast majority of efficiency analyses for higher education institutions have employed data envelopment techniques.[3] Due to the fact that universities are producers of at least two outputs – teaching and research – DEA seems to be an appropriate method. Early studies have predominantly examined the performance of single departments across universities since these are supposed to have similar structures. For instance, admitted research grants are subject to a faculty bias because some departments are more inclined to receive earnings from research grants (e.g. medicine or engineering) than others (e.g. languages).

The first studies were conducted for universities in Anglo-Saxon countries. Johnes and Johnes (1995) performed a cross-sectional investigation on the efficiency of economics departments in 36 British universities in the year 1989. Beasley (1997) also considered a single year (1992) to study the relative efficiency of chemistry and physics departments of 32 British universities. Madden and Savage (1997) used panel data in order to evaluate the efficiency of economics departments at Australian universities.

More recent studies have focused on evaluating entire universities since it is often associated with the availability of panel data in the first place, which in turn permits a study of efficiency change over time. Athanassapoulos and Shale (1997) analyzed the relative efficiency of 45 British universities for the years 1992/1993, indicating that there are significant differences across higher education institutions. Abbott and Doucouliagos (2003) considered 36 Australian public universities for their investigation. Flegg, Allen, Field, and Thurlow (2004) used data envelopment analysis to examine changes in technical efficiency of 45 British universities in the period 1981-1993.

However, whereas DEA is able to capture multiple outputs and multiple inputs at the same time, this method has its drawbacks. First, DEA does not account for stochastic noise in the data. For instance, the results may be severely biased when measurement errors are present. Second, in the DEA approach the heterogeneous structure of the university landscape - i.e. the department composition may differ considerably from one university to

[3] Worthington (2001) provides an extensive review on the efficiency analysis of universities.

another - cannot be adequately taken into account.[4] Stochastic frontier analysis permits accounting for faculty composition by including dummy variables for faculties. Although recent investigations applied SFA, e.g. Izadi, Johnes, Oskrochi, and Crouchley (2002) and Stevens (2005), these studies only partially accounted for faculty composition by distinguishing between arts students and science students. One drawback in the SFA is that it requires an assumption regarding the functional form of the cost or production function. The selection of a function is not a clear-cut task in higher eductaion as Kraus (2004) points out.

The efficiency of German higher education institutions has only recently been investigated by Warning (2004) and Warning (2005) applying DEA techniques. In these studies, the number of graduates as well as admitted research grants served as outputs. In addition, differentiated information on SSCI (Social Science Citation Index) and SCI (Science Citation Index) publication were taken as a research output whereas current expenditure and the number of professors were considered as inputs. However, possible changes in efficiency and/or technical change cannot be captured by these investigations due to the use of cross-sectional data. In particular, the use of cross-sectional data can be considered a problem in analyzing university efficiency due to the volatile output of publications or PhD completions. Research output often varies considerably over the years. Thus, efficiency scores based on cross-sectional data of adjacent periods may yield quite different results. The use of panel data should mitigate this problem.

Since our data set encompasses the period 1998-2003, we are able to extend the scope of efficiency analysis for the German university landscape. We will not only indicate the relative efficiency of universities for a specific year but also show to what extent total factor productivity has changed over time. In addition, we control for faculty composition of universities. Moreover, the efficiency scores from DEA and SFA will be compared in our study. Thus, we can offer a comprehensive picture on the efficiency of public higher education institutions in Germany.

[4] To some degree, accounting for faculty composition is possible within the DEA by distinguishing between arts/sciences in outputs (e.g. publications or graduates) and/or inputs (e.g. students), see Warning (2004). However, there is a limit to extending the number of inputs/outputs; introducing additional inputs/outputs reduces the number of benchmark universities and, as a result, an excessive number of universities will be indicated as efficient.

3 Data and Descriptive Statistics

In this section we will first describe our data set as well as specify our input and output variables. In a second step we will provide descriptive statistics on the universities in Germany.

We use data on public universities for the years 1998-2003 provided by the Federal Statistical Office of Germany. We confine our analysis to public universities since we are especially interested in the efficiency of public universities as set out in the introduction. In addition, private universities in Germany are highly specialized, i.e. oriented towards business management and/or medical studies, so that their inclusion represents a possible source of bias. For the same reason we also drop other specialized universities such as universities of fine arts and music. Universities of applied science are also excluded from our investigation since these are more oriented towards teaching instead of research. In particular, universities of applied science are in general not enabled to train doctoral students so that their consideration would have created a more heterogeneous sample.

The selection of input and output variables shows only limited variation in the studies on efficiency analysis of universities, since a university is in general assumed to accomplish two major duties. On the one hand, it is responsible for the production of human capital of the enrolled students. For this reason, we use the number of graduates as an approximation of the teaching output (see Table 1). On the other hand, the university serves as an organization in the field of research and development. Higher education institutions are involved in applied research, e.g. cooperating with private enterprises, as well as fundamental research in order to create knowledge. Research grants may be considered as a market price that gives information on the quality as well as on the quantity of research output, e.g. see Johnes (1997) and Koshal and Koshal (1999).[5]

The number of research personnel and the number of technical personnel serve as input variables. Additionally, other expenditures (total expenditures less wage spending) are incorporated as a third input variable. Alternatively to these three inputs, total costs less

[5] Previous investigations also specified the number of publications, in some cases weighted by journal ranks or the number of pages. However, due to data availability we did not include publications in our investigation. The number of students has been used ambiguously as an output of teaching activities or as an input into teaching production.

research grants will be used in the SFA approach. All monetary variables are deflated using the government consumption deflator as provided in the 2004/05 annual report of Council (2005).

Table 1: Input and output variables

Variable	Description of Variable
Outputs	
Graduates	Number of graduates
Grants	Amount of research grants
Inputs	
Technical staff	Number of technical personnel (DEA)
Research staff	Number of research personnel (DEA)
Current expenditure	Financial means (DEA)
Total costs - research grants	Total costs -research grants (SFA)

Source: Own represenation.

For an overview on the financial as well as personnel structure of German universities we report descriptive statistics in Table 2. Since the German states are responsible for education policy, we present the statistics at the state level. The ratios refer to single universities within the relevant state and represent the averages for the years 1998-2003. E and W denote East and West Germany, respectively. Hence, considering the ratio expenditure over graduates, we find that universities in East Germany display higher expenditures per graduate than their West German counterparts. With regard to the personnel endowment, we also observe that universities in East Germany have more research and total staff per graduate.

Table 2: Ratios of outputs and inputs in federal states

State (1998-2003)	$\frac{Expenditures}{Graduates}^{a)}$	$\frac{Research\ staff}{Graduates}$	$\frac{Total\ staff}{Graduates}$
Baden-Württemberg (W)	76.3	2.0	4.8
Bayern (W)	69.0	1.5	3.7
Berlin (E)	84.8	1.9	4.4
Brandenburg (W)	38.0	2.5	4.0
Bremen (W)	37.9	1.8	2.7
Hamburg (W)	66.7	1.7	4.0
Hessen (W)	59.9	1.6	3.9
Mecklenburg-Vorpommern (E)	127.4	2.6	7.7
Niedersachsen (W)	36.9	1.3	2.8
Nordrhein-Westfalen (W)	60.4	1.3	3.0
Rheinland-Pfalz (W)	44.8	1.4	3.1
Saarland (W	88.2	2.3	6.3
Sachsen (E)	75.3	2.2	5.0
Sachsen-Anhalt (E)	183.4	3.3	9.6
Schleswig-Holstein (W)	82.1	1.3	4.2
Thüringen (E)	82.5	2.3	5.7
a) measured in 1,000 € with base year 1995.			

Source: Federal Statistical Office of Germany; own calculations.

Due to differing faculty compositions, the universities in our sample are quite heterogeneous. Table 3 reveals these dissimilarities by grouping universities into sub-samples according to their faculty structure. Specifically, universities with engineering and medical faculties seem to have a different financial and personnel structure than universities without these two faculties. In the second line of Table 3 we included all 72 universities and calculated three different ratios with regard to the number of graduates. On average, a single university spends about 66,700 euros per year and per graduate in the considered time period 1998-2003. When restricting the sample to universities that have an engineering and a medical department, we find expenditures of 92,200 euros per graduate. Accordingly, higher education institutions without such cost-intensive faculties clearly spend the least money per graduate (17,800 euros). In addition, not only the financial but also the personnel endowment is higher among universities that offer studies in engineering and/or medicine.

Table 3: Ratios of outputs / inputs for different university samples

1998-2003	$\frac{Expenditure^{a)}}{Graduates}$	$\frac{\text{Research Staff}}{Graduates}$	$\frac{Total\ Staff}{Graduates}$
All universities	66.7	1.6	3.9
Universities			
engineering and medical faculty	92.2	2.1	5.3
no engineering faculty	71.2	1.5	3.9
no medical faculty	29.5	1.4	2.5
no engineering and no medical faculty	17.8	1.2	1.9

a) measured in 1,000 € with base year 1995.

Source: Federal Statistical Office of Germany; own calculations.

To summarize, descriptive statistics indicate that universities in East Germany have, on average, a higher endowment with regard to financial means and human resources. Universities that do not have an engineering and/or medical faculty spend considerably less and have less staff per graduate than universities with an engineering and/or a medical department.

4 Data Envelopment Analysis

4.1 Model Specification

In microeconomic theory it is usually assumed that production units operate efficiently. In particular, the decision making unit (DMU), e.g. a company or in our case a university, is supposed to allocate available capital and labor in such a way that no increase in the output level is possible without adding more inputs. Accordingly, given a specific output level, the DMU is supposed to use all inputs efficiently, i.e. no reduction in inputs is possible without diminishing the output level. However, in reality companies are subject to inefficiencies in the production of outputs as Coelli, Rao, O'Donnell, and Battese (2005) indicate.

In order to detect inefficiencies within companies in an industry, data envelopment analysis provides a suitable method. This non-parametric approach, which is based on linear programming assumes that the efficiency of a production unit can be measured by calculating the ratio of (weighted) outputs over (weighted) inputs. In other words, the main idea is to construct a non-parametric frontier over the available input and output data of the considered production units. The efficiency of a particular university can then be calculated relative to this frontier. Due to this general approach no functional form has to be assumed, which represents a considerable advantage compared to parametric methods. However, it is important to notice that only relative and not absolute efficiency is measured, i.e. the efficiency of a particular university is only calculated relative to the efficiency of the other higher education institutions in the sample. Efficient production units lie on the frontier whereas inefficient DMUs are envelopped by the frontier.

The choice of the input- or output-oriented approach in DEA is basically subject to the (possible) control of the administrator of the university. In the case of publicly funded higher education institutions in Germany, current expenditure as well as research and technical staff can be considered as given. Hence, the output oriented approach seems to be appropriate for our investigation, i.e. we assume that given the amount of inputs, the university pursues the maximization of its outputs.

By construction the efficiency scores of a university, e_k lie in the intervall $[0, 1]$. Thereby, a university k is said to be efficient if the efficiency score takes the value 1, i.e. it lies on the efficient frontier. Accordingly, an efficiency score below 1 implies that the university is inefficient compared to the other higher education institutions in the sample.[6]

The vector y_{rj} stands for the output r of university j whereas the vector x_{ij} represents the input i of university j (see equation 1). The parameter λ_j indicates the university-specific weight for the input and output factors, which are determined endogenously. Hence, the linear optimisation problem is solved, resulting in an efficiency score e_k for each university.

Restriction one and two in our DEA model (1) state that the reference universities produce at least as much of all outputs as the observed university. At the same time efficient universities do not consume as much input as the observed university. In addition, we introduce the restriction that the sum of the parameter λ_j equals 1, ensuring that variable returns to scale are possible. Otherwise constant returns to scale would be the benchmark

[6] See Banker, Cooper, Seiford, Thrall, and Zhu (2004) for a detailed presentation of the model.

case, assuming that every university already operates on the optimal scale level.The fourth and fifth restriction indicate that the weights as well as the inputs and outputs have to be positive, respectively. Since we are assuming, an output-oriented approach the inefficient university would have to increase its output by the factor $\frac{1}{e_k}$ in order to attain the efficient frontier.

$$
\begin{aligned}
& \max_{e,\lambda} \quad e_k \\
s.t. \quad & \sum_{j=1}^{n} y_{rj}\lambda_j \geq e_k y_{rk} \qquad (r = 1, 2, ..., s) \\
& \sum_{j=1}^{n} x_{ij}\lambda_j \leq x_{kj} \qquad (i = 1, 2, ..., m) \\
& \sum_{j=1}^{n} \lambda_j = 1 \qquad (j = 1, ..., n) \\
& \lambda_j \geq 0 \\
y_{rj}, x_{ij} \geq 0 \quad & (i = 1, 2, ..., m), (r = 1, 2, ..., s), (j = 1, ..., n)
\end{aligned}
\tag{1}
$$

Due to the availability of a panel data set, we are not only interested in the relative performance of a single university in a particular year but also in how the efficiency of universities have developed over time. Hence, we apply the Malmquist index, which is able to capture total factor productivity change from one year to another.[7]

The Malmquist index is constructed in such a way that the radial distance of observed output and input vectors in periods t and $t + 1$, relative to a reference technology, is measured. The output-oriented approach of the Malmquist index considers the maximum level of outputs with a given input vector and a given production technology relative to the observed outputs. To measure the distance between realized and hypothetical output, we use distance functions (d_t and d_{t+1}).

Applying the Malmquist index, the ratio of the distances of each data point relative to a common technology is calculated. In other words, we measure total factor productivity change over time. In order to avoid the necessity of choosing one of the time points as reference period, the geometric mean is calculated. A value of m greater than one indicates

[7] See Coelli et al. (2005) for a detailed presentation of the Malmquist index.

positive TFP growth from period t to period $t+1$, while a value less than one stands for a TFP decline.

$$m(y_{t+1,}x_{t+1}, y_t, x_t) = \left[\frac{d^t(y_{t+1}, x_{t+1})}{d^t(y_t, x_t)} * \frac{d^{t+1}(y_{t+1}, x_{t+1})}{d^{t+1}(y_t, x_t)}\right]^{1/2} \tag{2}$$

The use of the Malmquist index not only permits to measure total factor productivity change but we are also able to decompose this change into technical efficiency change and technical change, rearranging equation (2) as follows:

$$m(y_{t+1,}x_{t+1}, y_t, x_t) = \frac{d^{t+1}(y_{t+1}, x_{t+1})}{d^t(y_t, x_t)} \left[\frac{d^{t+1}(y_{t+1}, x_{t+1})}{d^t(y_t, x_t)} * \frac{d^t(y_{t+1}, x_{t+1})}{d^{t+1}(y, x)}\right]^{1/2} \tag{3}$$

The first term on the right-hand side in this equation represents the efficiency change while the term in brackets measures technical change.

4.2 Results

The results of the data envelopment analysis of German universities in the year 2003 are presented in Appendix A1 with an ordering of universities by their size, i.e. by the number of students. From the distribution of the efficiency scores, we conclude that large universities (e.g. University of Cologne, University of Munich) as well as small universities (e.g. TU Clausthal, University of Vechta) are operating on the efficient frontier. Hence, the size of a university is not necessarily associated with its efficiency.

With regard to the regional distribution, we find that some universities in East Germany are operating on the efficient frontier, e.g. FU Berlin, TU Berlin while others are inefficient, e.g. University of Magdeburg, University of Greifswald.[8] On average, the East German universities are less efficient than their West German counterparts.

Since data envelopment analysis does not consider the faculty composition of each university, efficiency scores are likely to suffer from a faculty bias. In descriptive statistics we

[8] Note that all three universities of Berlin are considered here as universities located in East Germany.

found that universities with a medical or engineering department display higher costs than the average university. Hence, in order to detect the impact of the faculty composition, we extend our investigation by taking university specific as well as environmental characteristics into account.

In a first step of our cross-sectional analysis, we calculated efficiency scores for every university. In a second step we regress the obtained efficiency scores on regional gross domestic product per capita.[9] We test the influence of regional GDP per capita on university efficiency since we consider GDP per capita an overall proxy for the characteristics of university location. The idea is that there might be beneficial or adverse effects from university location on efficiency due to spillovers. In particular, cooperations with research intensive companies in the region as well as the existence of laboratories, research institutions and big libraries or think tanks might result in positive spillover effects in regions with high GDP per capita. Alternatively, GDP per capita could prove to be cost enhancing due to wage/price elevating effects in agglomeration areas. In addition, we include dummy variables in the regression in order to control for the existence of an engineering and/or medical department for the reasons explained above. On the one hand, these two faculties are more expensive than other faculties; on the other hand, they earn more research grants on average than other faculties. Moreover, especially medical faculties (e.g. university hospitals) have a different structure when compared to other departments.

Since the efficiency scores are right-censored, we run cross-section Tobit regressions and for sensitivity checks also conduct ordinary least squares (OLS) regressions.[10] The estimation

[9] On the local level, Germany is divided into 434 regional authorities. Yet, a distinction has to be made since only about 75% of them can be characterized as districts ("Kreise"), comprising rural areas as well as villages and smaller cities. In contrast, the remaining quarter can be referred to as larger cities ("Kreisfreie Städte") This institutional peculiarity makes local GDP per capita a poor proxy for the location effect that we want to test because local GDP per capita is systematically biased downwards in cities that include surrounding areas. Thus, we choose regional GDP per capita at the level of "Raumordnungsregionen", which is supplied by the BBR (2006)

[10] Simar and Wilson (2006) indicate that results from the second stage, i.e. the regression of productive efficiency on environmental variables, might be subject to serial correlation within the efficiency estimates. They propose a double bootstrapping procedure that improves statistical efficiency in the second stage regression. However, in our study the second stage regression is accompanied by the estimates of the Battese and Coelli (1995) model, which can be considered as a sensitivity check to the results from the Tobit regression (see section 5).

results reveal that the coefficient for gross domestic product per capita is significant but only explains a small amount of the variation (see Table 4). Thereby, gross domestic product per capita has a positive influence on the efficiency of the universities. Hence, institutions of higher education that are located in economically prosperous regions are likely to benefit from the environment through spillover effects. This finding holds true for the OLS as well as for the Tobit regression. Including the dummy variables for engineering and medical faculties, we find both coefficients to be significant and negative. The existence of one of these faculties has a significant impact on the efficiency of a university. Hence, when analyzing relative efficiency among German universities the faculty composition should be taken into account.

Table 4: Results from cross-section OLS and Tobit regressions for the year 2003

	OLS		Tobit	
	(1)	(2)	(3)	(4)
Constant	0.775***	0.823***	0.759***	0.827***
	(13.46)	(14.15)	(9.26)	(10.09)
GDP per capita	0.004*	0.004**	0.006*	0.007*
	(1.71)	(2.00)	(1.86)	(2.08)
Medical faculty	-	-0.067**	-	-0.087*
		(-2.09)		(-1.97)
Engineering faculty	-	-0.071**	-	-0.087*
		(-2.22)		(-1.97)
Number of observations	72	72	72	72
R^2	0.04	0.14	0.23	0.63
Standard Errors in parentheses, p-value: * = 0.10, ** = 0.05, *** = 0.01				

Source: Own calculations.

In Appendix A2 we report results from the Malmquist index. On average, universities in East Germany display higher scores in total factor productivity change than their West German counterparts. For instance, the University of Potsdam or the TU Cottbus display values in TFP change above one. Note that no university in East Germany shows a TFP change below one, whereas some universities in West Germany, e.g. University of Köln or University of Passau, show a relatively strong decline. However, there are also West German universities that improved their total factor productivity during the considered time period, e.g. TU Darmstadt or TU Braunschweig.

Disentangling total factor productivity change into efficiency change and technical change, we find that the change in efficiency represents a main determinant of TFP change. Obviously, universities in Germany improved the allocation of financial means and/or adapted their spending, which resulted in a positive TFP change. In contrast, technical change was considerably low in the considered period

To summarize, the DEA results show that universities in East Germany have improved their efficiency considerably in the sample period. In this respect they also outperform the West German universities. With regard to the efficiency level, we find higher education institutions in the West to appear in top positions. Since Tobit regression results indicate that there are important differences in efficiency between universities that are due to university structure, in the following sectio we employ parametric techniques, which allow us to control for faculty composition by including dummy variables.

5 Stochastic Frontier Analysis

5.1 Model Specification

Since parametric techniques allow us to control for faculty composition by including dummy variables, we conduct a stochastic frontier analysis. As aforementioned, efficiency analysis in higher education has to take into account at least 2 outputs – research and teaching. This renders impossible estimating a production function, although the output-oriented approach is probably a more appropriate assumption for German universities (see section 4.1). Regarding research grants, universities clearly maximize the output with a given amount of input (staff/equipment). However, when looking at graduates, the adequate behavioural assumption is less clear-cut. Universities can only maximize the graduate output to a limited extent because the students are relatively free in their choice of universities and study time. The behavioural assumption is not undisputed and thus, we follow Izadi et al. (2002) and

Stevens (2005) in estimating a cost function.[11] Choosing a functional form for the cost function is not straightforward in higher education as pointed out by Kraus (2004). A functional form that offers a flexible functional relationship and especially allows factor substitution to be unrestricted should be applied. We use the translog cost function, which was also considered appropriate by Stevens (2005), for our investigation:

$$\ln C_{it} = \alpha + \theta_t t + \sum_{j=1}^{2} \beta_j \ln Q_{jit} + \frac{1}{2}\sum_{j=1}^{2}\sum_{k=1}^{2} \beta_{jk}(\ln Q_{jit} \ln Q_{kit}) + \kappa_1 \ln w_{it} + \kappa_2 \frac{1}{2}(\ln w_{it})^2$$

$$+\sum_{j=1}^{2} \kappa_{3j}(\ln w_{it} \ln Q_{jit}) + \omega_1 MED_{it} + \omega_2 MED_{it} \ln w_{it} + \sum_{j=1}^{2} \omega_{3j}(MED_{it} \ln Q_{jit}) \quad (4)$$

$$+\varphi_1 ENG_{it} + \varphi_2 ENG_{it} \ln w_{it} + \sum_{j=1}^{2} \varphi_{3j}(ENG_{it} \ln Q_{jit}) + \omega_4 MED_{it} ENG_{it} + u_{it} + v_{it}$$

In equation (4) i denotes universities. The sample period is from 1998 to 2003 and is referred to as t. C_{it} represents the costs in university i and time period t. As discussed above we choose total costs less research grants as our cost variable. Q_{it} denotes the same research and teaching outputs as described in the DEA section (graduates and research grants, j). Costs as well as research grants and the number of graduates are normalised by the number of students. As to wage or price information (w_{it}) we only have a limited access to data. Thus, we follow Stevens (2005) dividing total wage spending by the number of employees to get a proxy of wages. Wages for university employees are regulated at the federal level in Germany. However, our approach is able to capture differences in the structure of staff across universities: While some universities might prefer to employ a larger quantity of assistant professors and fewer full professors, other universities might have a higher density of full professors with a smaller number of total research/teaching staff. MED and ENG are dummy variables that control for the faculty composition of universities, specifically for medical and engineering faculties. As a sensitivity check, we also estimate the model,

[11] We choose to estimate a cost function compared to a distance function as we prefer to interpret the coefficients - especially the coefficients from the faculty controls - in the intuitive context of a cost function.

excluding the controls for faculty structure. Additionally, we include a constant (α) and a linear time trend (t) to account for technological change.[12]

v_{it} in equation (4) denotes an error term which is i.i.d. $N(0, \sigma_v^2)$ and independent of u_{it}, where u_{it} represents a non-negative random variable that is assumed to display cost inefficiency in the production of teaching/research in university education. Specifically, u_{it} displays total economic inefficiency, i.e. technical inefficiency plus allocative inefficiency. We follow the Battese and Coelli (1995) methodology assuming u_{it} to be independently distributed and following a truncated normal distribution:[13] $N(\mu_{it}, \sigma_u^2)$. The Battese and Coelli (1995) model permits to test hypotheses with respect to the determinants of inefficiency, i.e. μ_{it} is assumed to be determined by Z_{it} variables:

$$\mu_{it} = \delta Z_{it} \tag{5}$$

Z_{it} denote structural/environmental variables that might play an important role in the production of teaching/research but that typically cannot be influenced directly by the university. We select regional GDP per capita as a proxy for beneficial or adverse effects from university location (see section 4.2). Moreover, we include a linear time trend as an environmental variable to account for efficiency change over time. Information about the share of deviations from the cost function that are due to inefficiencies is reported by:

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2} \tag{6}$$

Consequently, if γ is zero, all deviations are caused by noise rather than inefficiency; if γ is one, all deviations are due to inefficiencies.

[12] Unfortunately, we are not able to include a proxy for incoming students' educational background. This information is impossible to obtain in Germany as there is no general admission test procedure.

[13] Truncated at zero to display inefficient performances "above" the estimated cost function, see also Coelli (1996)

5.2 Results

Table 5 reports the results from the estimation of the cost function. The estimation results indicate that the controls for faculty composition, i.e. the dummies for engineering and medical faculties, are significant at the 5% and 1% level, respectively. The specification with faculty dummies is also strongly supported by a likelihood ratio test, which rejects the null hypothesis of the dummy variables and interaction terms being restricted to zero at every conventional significance level (see Table 6). Thus, we consider the model with faculty controls as our baseline model. As suggested by the descriptive statistics, costs in universities with these faculties are higher than in universities without engineering or medical faculties.

In addition, several of the interaction terms of faculty dummies with output/wage variables are significant, indicating that universities with medical and/or engineering faculties not only have different cost levels but also different marginal cost structures. For instance, research grants only substitute for state money in universities with engineering faculties whereas this effect is not significant in universities without medical and engineering faculty. In universities with medical faculties, research grants even crowd in additional state funds.[14]

Not controlling for the faculty composition of universities significantly biases the estimation results and thus the predictions for university level efficiency scores. This can be seen by comparing the two models in Table 5. For instance, in the model without controls for faculty composition, research grants have a highly significant and highly positive effect on total costs less research grants (4.41). However, after controlling for faculty structure, this effect decreases significantly in size and turns insignificant. Moreover, a negative effect of the number of graduates on total costs disappears after controlling for faculty structure.

Both models suggest that there is a strong negative effect of wages per employee on costs. The model without dummies indicates that a one percent increase in wages per employee results in a 12.7% decrease in costs per student. Of course, this effect could be due to cost savings that arise from high quality staff. However, after controlling for faculty composition, this effect declines to about 7.3%.

[14] A one percent increase in research grants per student decreases total costs less research grants (divided by the number of students) by 0.21% in universities with engineering faculties. In universities with medical faculties, a one percent increase in research grants per student increases total costs less research grants (per student) by 0.11%.

Table 5: Maximum Likelihood Estimates of the Cost Function Coefficients

Coeffiicient	Baseline model	Model without dummies
Constant	13.02**	20.11**
	(2.38)	(2.00)
Time	-0.004	0.02
Linear time trend	(0.41)	(1.22)
RG	0.56	4.41***
Research grants divided by the number of students	(0.80)	(7.07)
GRA	-0.33	-3.36*
Final degrees completed divided by the number of students	(0.25)	(1.65)
RGSQ	0.29***	0.08
RG^2	(4.66)	(1.31)
GRASQ	0.58***	0.08
GRA^2	(3.27)	(0.29)
RGGRA	-0.46***	-0.17*
RG * GRA	(6.78)	(1.75)
W	-7.33***	-12.69***
Wage spending per university employee	(2.95)	(2.64)
WNWSQ	2.67***	4.30***
W^2	(4.50)	(3.71)
WNWRG	-0.34*	-1.20***
WNW * RG	(1.90)	(7.20)
WNWGRA	0.57**	1.06**
WNW * GRA	(1.97)	(2.33)
ENG	2.17**	-
Engineering faculty: yes = 1, no = 0	(1.98)	
MED	3.90***	-
Medical faculty: yes = 1, no = 0	(3.30)	
MEDENG	-0.16**	-
MED * ENG	(2.11)	

continued		
Coefficient	Baseline Model	Model without Dummies-
ENGRG	-0.21***	-
ENG * RG	(2.98)	
ENGGRA	0.25**	-
ENG * GRA	(2.18)	
ENGW	-0.44	-
ENG * W	(1.47)	
MEDRG	0.11*	-
MED * RG	(1.74)	
MEDGRA	-0.04	-
MED * GRA	(0.32)	
MEDW	-0.93***	-
MED * W	(2.71)	
Gamma	0.99***	0.95***
	(145.70)	(48.80)
Log-Likelihood	-36.31	-255.07
Note: Endogenous variable is (TC - Research Grants) divided by the number of students.		
t-statistics in parentheses, p-value: * = 0.10, ** = 0.05, *** = 0.01		

Sources: All data has been supplied by the Federal Statistical Office of Germany with the exception of GDP data, which has been taken from Bundesamt für Bauwesen und Raumordnung (2006). C, RG and W have been deflated using the government consumption deflator supplied by the German Council of Economic Experts (2005); GDP has been deflated using the GDP deflator from the same source.

Thus, faculty composition accounted for nearly half of this effect. Medical and engineering faculties employ an increased number of lower cost staff when compared to other faculties, e.g. nurses or technical staff. At the same time, these faculties have higher costs as shown in the descriptive statistics. Accounting for faculty composition therefore reduces this cross-section variation. In part, the remaining effect could be due to differences between social sciences and sciences.

Table 6: Likelihood ratio - test of faculty restrictions

Null hypothesis	$\chi^2_{0.99}$	Test statistic
H_0:ω_1=ω_2=ω_{31}=ω_{32}=φ_1=φ_2=φ_{31}=φ_{32}=ω_4= 0	21.67	437.5

The LR test statistic is given by -2{ln[Likelihood(H_0)-ln[Likelihood(H_1)]}, where H_0 denotes the model without dummy variables and H_1 denotes the model including faculty dummies. This statistic has asymptotically a chi-square distribution with degrees of freedom equal to 9 (parameters assumed to be zero), see Berndt (1991). The ln(Likelihood) can be obtained from Table 5.

The model with faculty dummies as well as the model without dummy variables both indicate that there are economies of scope between teaching and research. This effect increases in size and significance after controlling for faculty structure (-0.46). In both models the gamma coefficient is high. After controlling for faculty structure the share of deviations that is due to inefficiencies increases from 95% to 99%, indicating almost all deviations from the cost function are caused by inefficiency.

Table 7 presents the results for the influence of environmental variables on university efficiency. There is weak evidence that regional GDP per capita might have a positive effect on efficiency although the effect is not statistically significant. This suggests that universities could indeed benefit from positive spillover effects as discussed in section 4.2. This prediction is in accordance with the results from the Tobit regression (see Table 4). Recall that efficiency scores that are based on a cost function are bound between 1 and ∞. An efficiency score of 1 denotes an efficient performance. The efficiency scores obtained from the DEA are bound between 0 and 1 where 1 indicates an efficient performance.

Thus, in fact, the results from the Tobit regression and the determinants of inefficiency in the Battese and Coelli (1995) model both indicate that regional GDP per capita has a beneficial effect on university efficiency. However, this effect is not statistically significant at reasonable levels of significance in the SFA specification. The coefficient of the time trend suggests that universities improved their efficiency in the sample period. But again, this effect is only significant at the 15% level in the baseline model and at the 10% level in the model without faculty controls

Table 7: Impact of environmental variables

Coefficient	Baseline model	Model without dummies
Constant	23.71 (1.17)	15.56 (0.95)
Time trend	-0.76 (1.54)	-0.06 (1.90)*
Regional GDP p.c.	-3.01 (1.21)	-0.08 (0.49)
LR of the one-sided error	31.56	29.29
t-statistics in parentheses, p-values: * = 0.10, ** = 0.05, *** = 0.01		

Source: Own calculations.

Appendix B reports the predictions for the university level efficiency scores based on our baseline model. We do not discuss the university level efficiency scores in detail. However, the efficiency predictions suggest that East German universities improved their efficiency performance considerably from 1998 to 2003 and are catching up with the West German universities (see Table 8). However, West German universities were still more efficient in 2003.

Table 8: Efficiency scores: Mean efficiency of East and West German universities

	1998	1999	2000	2001	2002	2003
East German universities	1.66	1.62	1.50	1.35	1.35	1.30
West German universities	1.35	1.34	1.34	1.31	1.28	1.25
Note: Efficiency predictions based on baseline cost function model as set out in Table 5.						

Source: Own calculations.

6 Comparison of DEA and SFA results

Although data envelopment and stochastic frontier analysis are quite different approaches to efficiency analysis and although our models differ considerably in assumptions and even in input and output definitions, we found many similarities concerning the efficiency performance of German universities. This is also confirmed by the correlation coefficients for the efficiency scores obtained from DEA and SFA, which are significantly and positively correlated by up to 60%.

One robust result of our investigation is that East German universities only appear in medium ranking positions, i.e. in the year 2003 they are still less efficient than the higher education institutions in West Germany. This finding is also consistent with the cross-sectional evidence presented by Warning (2005) for the year 1998. However, focusing on total factor productivity in the years 1998 to 2003 we find that East German universities have outperformed their West German counterparts. Thereby, both the Malmquist index as well as the SFA models suggest that the main determinant has been efficiency change rather than technological change.

With regard to university location, Tobit regression results as well as our SFA model indicate that regional GDP per capita has a small but positive impact on the efficiency of higher education institutions. Thus, universities that are located in a relatively rich region benefit from their environment probably due to spillover effects.

Accounting for faculty composition of German universities revealed that those institutions with medical and/or engineering faculty not only have higher cost levels but also different marginal cost structures. In our stochastic frontier analysis, not accounting for university faculty composition biases the cost function estimates in several aspects and thus gives biased efficiency scores. Besides the evidence presented for German universities, our discussion of the results from Tobit regression of DEA efficiency scores as well as the introduction of faculty controls in the stochastic frontier analysis might be an important contribution to the efficiency analysis of higher education institutions. At least for German universities, Tobit regression and SFA faculty controls suggest that DEA is not an appropriate technique to analyse efficiency at the level of entire universities. While it may be appropriate for the efficiency analysis of single university departments, we suggest that entire universities are too heterogeneous to be compared using non-parametric methods.

7 Conclusions

The present empirical investigation is the first approach to apply data envelopment as well as stochastic frontier techniques to a panel data set of 72 German universities over the years 1998-2003. We find that accounting for faculty composition is fundamental for obtaining unbiased efficiency scores. Thus, our model and the evidence presented for Germany suggest that results from earlier studies, which analysed the efficiency of entire universities without accounting for faculty structure might be biased.

With respect to German universities, our estimation results indicate that total factor productivity has been increasing more rapidly in East German universities compared to their West German counterparts. Due to the upcoming demographic changes – the number of high-school graduates in East Germany is expected to decrease by about 40% within the next 15 years – the universities in East Germany must continue their good dynamic efficiency performance. On a university level West German universities appear at the top end of our efficiency rankings.

Efficiency rankings of German universities have several channels by which university performance could be improved. On the one hand, university management is informed about its own performance in the first place and can thus implement measures to improve efficient spending of funds. On the other hand, state governments could distribute at least a share of public funds according to university efficiency performance, rewarding efficient allocation and creating an atmosphere of competition in the German public university system. Moreover, the current introduction of tuition fees will bring about a third channel: Students will demand that their fees be spent efficiently. In short, the very existence of efficiency rankings of German public universities and a recurrent update could contribute to improve the allocation of public resources in higher education.

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Appendix A1

DEA for the year 2003 with variable returns to scale ordered by number of students

University	Score	Students	East / West
U Köln	1.000	59,777	W
U München	1.000	46,203	W
Fernuni Hagen	0.558	42,980	W
U Münster	1.000	42,490	W
U Frankfurt a.M.	0.900	42,420	W
FU Berlin	1.000	41,255	W
U Hamburg	0.852	39,250	W
U Bonn	0.830	37,059	W
HU Berlin	0.825	36,782	E
U Bochum	0.917	35,703	W
U Mainz	0.718	33,222	W
TU Dresden	0.936	31,155	E
TH Aachen	1.000	30,742	W
TU Berlin	1.000	30,548	E
U Leipzig	0.735	28,398	E
U Dortmund	0.935	25,440	W
U Düsseldorf	0.713	25,176	W
U Heidelberg	0.924	24,745	W
U Hannover	1.000	24,152	W
U Erlangen-Nürnberg	0.709	23,161	W
U Göttingen	0.792	23,011	W
U Gießen	0.666	22,121	W
U Bremen	1.000	21,706	W
U Tübingen	0.739	21,010	W

University	Score	Students	East / West
U Freiburg i.Br.	0.614	20,737	W
TU Darmstadt	0.855	20,588	W
U Kiel	0.813	20,193	W
U Bielefeld	0.836	19,891	W
TU München	1.000	19,887	W
U Stuttgart	1.000	19,452	W
U Marburg	0.645	19,332	W
U Jena	0.560	19,229	E
U Kassel	0.961	18,582	W
U Würzburg	0.670	18,183	W
U Halle	0.525	17,355	E
U Regensburg	0.663	17,215	W
U Potsam	0.668	16,409	W
U Karlsruhe	0.668	16,409	W
U Saarbrücken	0.478	14,933	W
U Wuppertal	0.724	14,652	W
U Augsburg	1.000	14,181	W
U Paderborn	0.948	13,897	W
TU Braunschweig	0.873	13,501	W
U Rostock	0.553	13,501	E
U Trier	0.949	12,582	W
U Siegen	0.696	12,220	W
U Mannheim	1.000	12,184	W
U Oldenburg	0.857	11,220	W

University	Score	Students	East / West
U Magdeburg	0.575	11,175	E
U Osnabrück	0.628	10,678	W
U Koblenz-Landau	1.000	10,001	W
TU Chemnitz	0.803	9,757	E
U Greifswald	0.419	8,934	E
U Konstanz	0.776	8,891	W
U Bayreuth	0.730	8,726	W
TU Kaiserslautern	0.908	8,450	W
U Bamberg	1.000	8,153	W
U Passau	0.817	8,002	W
TU Ilmenau	0.787	7,578	E
U Ulm	0.680	6,767	W
U Lüneburg	1.000	6,748	W
TU Hamburg-Harburg	0.891	5,689	W
U Frankfurt (Oder)	1.000	5,158	E
U Hohenheim	0.758	5,072	W
TU Cottbus	0.796	4,735	E
U Weimar	0.850	4,640	E
TU Freiberg	1.000	4,181	W
U Hildesheim	1.000	3,674	W
U Bund München	0.645	2,903	W
TU Clausthal	1.000	2,717	W
H Vechta	1.000	2,223	W
U Bund Hamburg	1.000	1,888	W

Appendix A2

Malmquist-Index for the years 1998-2003 ordered by number of students

University	TFP Change	Efficiency Change	Technical Change	Students	East / West
U Köln	0.986	0.982	1.004	59,777	W
U München	1.017	1.023	0.995	46,203	W
Fernuni Hagen	0.923	0.942	0.980	42,980	W
U Münster	1.024	1.021	1.004	42,490	W
U Frankfurt a.M.	1.013	1.015	0.997	42,420	W
FU Berlin	1.053	1.055	0.999	41,255	W
U Hamburg	1.038	1.040	0.998	39,250	W
U Bonn	1.026	1.032	0.994	37,059	W
HU Berlin	1.063	1.074	0.989	36,782	E
U Bochum	1.017	1.028	0.989	35,703	W
U Mainz	1.012	1.016	0.996	33,222	W
TU Dresden	1.041	1.051	0.990	31,155	E
TH Aachen	1.010	1.030	0.980	30,742	W
TU Berlin	1.024	1.038	0.987	30,548	E
U Leipzig	1.049	1.048	1.001	28,398	E
U Dortmund	0.962	0.990	0.972	25,440	W
U Düsseldorf	1.052	1.055	0.997	25,176	W
U Heidelberg	1.058	1.074	0.985	24,745	W
U Hannover	0.952	0.973	0.978	24,152	W
U Erlangen-Nürnberg	0.952	0.961	0.991	23,161	W
U Göttingen	0.988	0.998	0.990	23,011	W
U Gießen	1.034	1.037	0.998	22,121	W
U Bremen	1.056	1.036	1.019	21,706	W
U Tübingen	1.008	1.020	0.988	21,010	W

University	TFP Change	Efficiency Change	Technical Change	Students	East / West
U Freiburg i.Br.	1.003	1.016	0.987	20,737	W
TU Darmstadt	1.125	1.144	0.983	20,588	W
U Kiel	1.010	1.013	0.997	20,193	W
U Bielefeld	1.009	1.035	0.976	19,891	W
TU München	1.007	1.016	0.991	19,887	W
U Stuttgart	0.992	1.000	0.992	19,452	W
U Marburg	1.017	1.018	0.999	19,332	W
U Jena	1.055	1.063	0.992	19,229	E
U Kassel	1.013	1.035	0.979	18,582	W
U Würzburg	0.945	0.953	0.992	18,183	W
U Halle	1.046	1.056	0.991	17,355	E
U Regensburg	0.979	0.980	0.999	17,215	W
U Potsdam	1.080	1.076	1.005	16,409	E
U Karlsruhe	1.013	1.000	1.013	16,409	W
U Saarbrücken	0.979	0.985	0.994	14,933	W
U Wuppertal	0.959	0.989	0.969	14,652	W
U Augsburg	0.964	0.996	0.968	14,181	W
U Paderborn	0.971	0.993	0.978	13,897	W
TU Braunschweig	1.072	1.078	0.995	13,501	W
U Rostock	0.973	0.970	1.003	13,501	E
U Trier	1.006	1.035	0.972	12,582	W
U Siegen	0.937	0.961	0.976	12,220	W
U Mannheim	1.034	1.060	0.976	12,184	W
U Oldenburg	1.023	1.043	0.980	11,220	W

University	TFP Change	Efficiency Change	Technical Change	Students	East / West
U Magdeburg	1.111	1,120	0.992	11,175	E
U Osnabrück	0.919	0,947	0.970	10,678	W
U Koblenz-Landau	0.956	0,976	0.979	10,001	W
TU Chemnitz	1.031	0,999	1.032	9,757	E
U Greifswald	1.044	1,049	0.995	8,934	E
U Konstanz	1.016	1,045	0.972	8,891	W
U Bayreuth	0.980	0,991	0.990	8,726	W
TU Kaiserslautern	1.009	1,013	0.996	8,450	W
U Bamberg	0.958	1,000	0.958	8,153	W
U Passau	0.934	0,963	0.970	8,002	W
TU Ilmenau	1.083	1,072	1.010	7,578	E
U Ulm	1.089	1.099	0.991	6,767	W
U Lüneburg	1.021	1.033	0.988	6,748	W
TU Hamburg-Harburg	1.036	1.056	0.981	5,689	W
U Frankfurt (Oder)	1.051	1.074	0.979	5,158	E
U Hohenheim	1.036	1.053	0.984	5,072	W
TU Cottbus	1.041	1.028	1.012	4,735	E
U Weimar	1.054	1.090	0.967	4,640	E
TU Freiberg	1.044	1.028	1.016	4,181	W
U Hildesheim	0.969	1.006	0.963	3,674	W
U Bund München	1.064	1.072	0.993	2,903	W
TU Clausthal	0.995	1.000	0.995	2,717	W
H Vechta	0.929	0.962	0.965	2,223	W
U Bund Hamburg	1.065	1.047	1.017	1,888	W

Appendix B

SFA Ranking based on mean efficiency over the period 1998-2003 (Baseline Model) ordered by number of students

University	Mean	1998	1999	2000	2001	2002	2003	Students	East / West
U Köln	1.09	1.08	1.09	1.08	1.08	1.12	1.09	59,777	W
U München	1.14	1.18	1.18	1.15	1.14	1.12	1.09	46,203	W
Fernuni Hagen	1.26	1.54	1.56	1.17	1.10	1.11	1.10	42,980	W
U Münster	1.21	1.18	1.26	1.21	1.17	1.26	1.17	42,490	W
U Frankfurt a.M.	1.10	1.05	1.06	1.08	1.10	1.16	1.17	42,420	W
FU Berlin	1.08	1.12	1.10	1.08	1.05	1.06	1.05	41,255	W
U Hamburg	1.16	1.18	1.17	1.23	1.13	1.10	1.13	39,250	W
U Bonn	1.23	1.28	1.30	1.21	1.16	1.20	1.22	37,059	W
HU Berlin	1.34	1.65	1.55	1.30	1.23	1.,17	1.16	36,782	E
U Bochum	1.05	1.04	1.05	1.05	1.04	1.07	1.06	35,703	W
U Mainz	1.20	1.26	1.25	1.17	1.16	1.19	1.15	33,222	W
TU Dresden	1.15	1.19	1.19	1.13	1.11	1.15	1.11	31,155	E
TH Aachen	1.11	1.11	1.16	1.14	1.12	1.08	1.07	30,742	W
TU Berlin	1.23	1.20	1.30	1.27	1.27	1.20	1.15	30,548	E
U Leipzig	1.39	1.52	1.53	1.54	1.31	1.26	1.18	28,398	E
U Dortmund	1.14	1.09	1.12	1.10	1.11	1.21	1.21	25,440	W
U Düsseldorf	1.40	1.53	1.38	1.24	1.35	1.57	1.32	25,176	W
U Heidelberg	1.17	1.21	1.25	1.25	1.13	1.09	1.07	24,745	W
U Hannover	1.10	1.07	1.07	1.09	1.11	1.14	1.13	24,152	W
U Erlangen-Nürnberg	1.20	1.18	1.11	1.18	1.25	1.23	1.25	23,161	W
U Göttingen	1.23	1.18	1.19	1.49	1.14	1.13	1.22	23,011	W
U Gießen	1.41	1.53	1.58	1.45	1.50	1.22	1.19	22,121	W
U Bremen	1.08	1.13	1.10	1.08	1.06	1.06	1.04	21,706	W
U Tübingen	1.15	1.15	1.16	1.13	1.18	1.11	1.14	21,010	W

University	Mean	1998	1999	2000	2001	2002	2003	Students	East / West
U Freiburg i.Br.	1.17	1.30	1.27	1.15	1,10	1.09	1.10	20,737	W
TH Darmstadt	1.35	2.05	1.51	1.15	1.14	1.12	1.12	20,588	W
U Kiel	1.66	1.81	1.70	1.82	1.52	1.49	1.63	20,193	W
U Bielefeld	1.19	1.21	1.20	1.17	1.14	1.19	1.22	19,891	W
TU München	1.12	1.12	1.12	1.11	1.11	1.13	1.11	19,887	W
U Stuttgart	1.09	1.08	1.13	1.12	1.07	1.08	1.06	19,452	W
U Marburg	1.33	1.45	1.37	1.32	1.29	1.26	1.27	19,332	W
U Jena	1.37	1.54	1.48	1.40	1.32	1.29	1.22	19,229	E
GH Kassel	1.20	1.19	1.23	1.31	1.26	1.14	1.08	18,582	W
U Würzburg	1.11	1.16	1.17	1.10	1.05	1.09	1.10	18,183	W
U Halle	2.04	2.40	2.28	2.09	2.03	1.83	1.64	17,355	E
U Regensburg	1.14	1.20	1.19	1.16	1.13	1.09	1.09	17,215	W
U Potsdam	1.28	1.53	1.52	1.28	1.14	1.10	1.11	16,409	E
U Karlsruhe	1.11	1.08	1.08	1.13	1.15	1.12	1.10	16,409	W
U Saarbrücken	1.95	1.89	2.13	2.00	1.79	1.92	1.96	14,933	W
U-GH Wuppertal	1.27	1.12	1.18	1.18	1.30	1.32	1.49	14,652	W
U Augsburg	1.11	1.16	1.09	1.10	1.11	1.08	1.10	14,181	W
U-GH Paderborn	1.09	1.09	1.08	1.08	1.08	1.12	1.09	13,897	W
U Rostock	2.11	2.28	2.25	2.21	1.90	2.06	1.97	13,501	W
TU Braunschweig	1.23	1.12	1.14	1.24	1.24	1.33	1.32	13,501	E
U Trier	1.11	1.10	1.15	1.12	1.09	1.10	1.07	12,582	W
U-GH Siegen	1.27	1.13	1.16	1.20	1.24	1.40	1.50	12,220	W
U Mannheim	1.22	1.29	1.31	1.21	1.27	1.14	1.10	12,184	W
U Oldenburg	1.30	1.55	1.32	1.32	1.22	1.23	1.18	11,220	W

University	Mean	1998	1999	2000	2001	2002	2003	Students	East / West
U Magdeburg	2.05	2.54	2.33	1.87	1.87	1.91	1.75	11,175	E
U Osnabrück	1.31	1.17	1.20	1.27	1.46	1.32	1.46	10,678	W
U Koblenz-Landau	1.14	1.08	1.10	1.18	1.12	1.20	1.17	10,001	W
TU Chemnitz	1.34	1.63	1.41	1.35	1.24	1.22	1.18	9,757	E
U Greifswald	1.81	2.20	2.19	1.96	1.56	1.44	1.53	8,934	E
U Konstanz	1.25	1.39	1.37	1.29	1.20	1.19	1.09	8,891	W
U Bayreuth	1.12	1.11	1.17	1.13	1.11	1.12	1.09	8,726	W
U Kaiserslautern	1.12	1.12	1.11	1.12	1.16	1.15	1.10	8,450	W
U Bamberg	1.22	1.14	1.19	1.29	1.30	1.22	1.17	8,153	W
U Passau	1.18	1.12	1.11	1.24	1.13	1.17	1.30	8,002	W
TU Ilmenau	1.53	1.89	1.82	1.57	1.24	1.35	1.30	7,578	E
U Ulm	3.97	4.76	4.52	4.39	3.78	3.32	3.08	6,767	W
U Lüneburg	1.12	1.14	1.13	1.11	1.11	1.15	1.10	6,748	W
TU Hamburg-Harburg	1.37	1.49	1.59	1.37	1.26	1.20	1.34	5,689	W
U Frankfurt (Oder)	1.11	1.12	1.14	1.12	1.08	1.11	1.09	5,158	E
U Hohenheim	1.47	1.68	1.52	1.48	1.36	1.51	1.25	5,072	W
TU Cottbus	1.41	1.46	1.63	1.60	1.20	1.31	1.27	4,735	E
U Weimar	1.45	1.75	1.65	1.60	1.20	1.32	1.18	4,640	E
TU Freiberg	1.16	1.16	1.20	1.15	1.15	1.11	1.20	4,181	W
U Hildesheim	1.59	1.38	1.62	1.68	1.81	1.83	1.23	3,674	W
U Bund München	2.52	2.80	2.50	2.68	3.04	2.28	1.83	2,903	W
TU Clausthal	1.27	1.24	1.34	1.30	1.25	1.25	1.22	2,717	W
H Vechta	1.53	1.30	1.05	1.81	1.78	1.69	1.57	2,223	W
U Bund Hamburg	1.45	1.51	1.62	1.58	1.65	1.25	1.06	1,888	W

Note that efficiency scores that are based on cost function estimates range from 1 to ∞; a score of 1 indicates an efficient performance.

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